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Gamma Radiation as a Function of Distance

Project 13.3a.

October 1955

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FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

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ABSTRACT

Gamma radiation exposure measurements were made as a function of distance on the Bee, Apple I, Wasp Prime, Apple II, and Zucchini shots of Operation Teapot. The Apple I, Wasp Prime, and Zucchini gamma measurements scaled with yield, the Bee results were high by about 50%, and the Apple II measurements were affected by the clouds passing over the instrument line. The measurements made with the LASL aluminum-wood and the NBS lead-tin-Bakelite film badges are compared with the energy-independent Victoreen thimble chamber readings. The approximate film values relative to thimble chamber values are the following: in the aluminum badge, film types 502 and 510 were 10% high, and types 606 and 1290 were 20% high; in the NBS badge, 502 was 7% low, 510 was 19% low, 606 was 10% low, and 1290 was essentially correct.

ACKNOWLEDGEMENTS

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CONTENTS

1. Introduction

During Nevada operations prior to Teapot, both the Evans Signal Laboratory (ESL) and the Los Alamos Scientific Laboratory (LASL) measured gamma radiation as a function of distance on many of the shots, using film badges. The measurements of the two laboratories have not been in agreement, the LASL values being generally higher than the ESL values. In 1953 an intercalibration between LASL and the National Bureau of Standards (NBS) revealed an error of 13% in the LASL measurements, but the major portion of the discrepancy has remained unresolved.

Since the primary purpose of the LASL measurements was to determine whether the gamma radiation from the various devices tested on these operations scaled with yield, which is a relative determination, no correction for this calibration error was made nor were further attempts made at finding additional errors. However, prior to the Teapot operation it became apparent that there was a need for a clarification of the results, including a determination of absolute exposure values. The widely differing response of the ESL and LASL badges to low energy gamma radiation appeared to be a likely source of error in both ESL and LASL measurements. It was therefore decided to compare film badge measurements with those obtained with Victoreen thimble chambers, which are essentially independent of energy above 30 kev.

2. Methods and Procedures

2.1 Film Types

The film types employed on previous tests by the two groups and their approximate exposure ranges are as follows:

Exposure range, r	LASL film type	ESL film type
0.1 - 10	Du Pont 502	Du Pont 508
1 - 20	Du Pont 510	Du Pont 510
15 - 200	Du Pont 606	Du Pont 606
20 - 1000	Du Pont 1290 (Adlux)	Du Pont 1290 (Adlux)
1000 - 10,000	Eastman 548-0	Eastman 548-0

It should be noted that the film types are identical with the exception of the lowest exposure range, where LASL used type 502 and ESL used type 508. Of the six film types listed above, only Du Pont 502, 510, 606, and 1290 were used on Operation Teapot. An attempt was made by LASL to obtain some Du Pont 508 film from the ESL group in Nevada during the operation, but ESL had discontinued using this film type after Operation Upshot-Knothole and was using Du Pont 502. The high-range Eastman 548-0 had been used only to a limited extent by LASL on previous tests and consequently was not included in the Teapot measurements.

2.2 Film Badges

The film badge used by LASL consists of a slotted wooden cylinder 2-5/8 in. in diameter and 6 in. in length enclosed in a 1/16 in. thick aluminum can mounted on an angle-iron stake. This badge will be referred to as the aluminum-wood or AW badge.

The film badge used by ESL consists of a Bakelite container having an 8.25 mm wall thickness covered with layers of 1.07 mm of tin and 0.3 mm of lead. A 0.78 mm thick lead strip is wrapped around the outer edge of the badge and the entire assembly is placed in a plastic cigarette case and mounted on a metal stake. This badge, designed by Ehrlich of the National Bureau of Standards, is usually referred to as the NBS badge.

Three other badges were used to some extent on Teapot. One of these, which will be called the B-C badge, consisted of two separate filters, each filter containing varying amounts of six elements. Although this badge is still in the design stage, the decision was made to use it because of its somewhat unique response in the very low energy region.

At the request of Joe Deal of the AEC, a film badge constructed by Edgerton, Germeshausen, and Grier (EG&G), and a film badge used by the British on their test operations were also used. The EG&G badge is similar in design to the NBS badge except that the Bakelite container has been replaced with a polyethylene container. The British badge consists of a 1.0 mm tin filter and a thin plastic jacket; Ilford film type PM 3 was used with this badge.

The five film badges used on Teapot are shown in Fig. 1.

2.3 Film Calibration

The films used by LASL in the AW badge have been calibrated in the past with radiation from a 22 Mev betatron. In 1953, an intercalibration was performed in which film types 1290 and 606 were exposed in the NBS and AW badges to radiation from NBS and LASL betatrons operating at peak energies of 10 and 22 Mev, respectively. To eliminate possible inconsistencies in developing, two sets of exposures were made and each laboratory processed a complete set of 10 and 22 Mev film calibrations with essentially identical results. The results, reported in NBS Report 8A-121, showed that the films in the NBS and AW badge have the same response to 10 Mev radiation. The film response of the NBS badge at 22 Mev was somewhat high, but this effect does not influence the field discrepancy since ESL did not calibrate at this high energy. The film response in the AW badge was found to be 13% lower at 22 Mev than at 10 Mev, and subsequent measurements at LASL demonstrated that the thickness of aluminum and wood in the badge was not sufficient to provide ionic equilibrium at the higher energies. This 13% lower response at the 22 Mev calibration energy means that the interpreted field measurements were high by this amount, because distances from the source were great enough to provide ionic equilibrium.

Two different radium sources were used for calibrating the film badges for Operation Teapot, one approximately 0.2 curies and the other approximately 2.3 curies. The rhm (roentgens per hour at 1 meter) of the 0.2 curie source had been measured by NBS to within $\pm$1%. The 2.3 curie

source was calibrated by comparing the current it produced in a Victoreen thimble chamber attached to a vibrating-reed electrometer to the current produced under identical conditions by the known 0.2 curie source. After the operation, both sources were again measured using Victoreen thimble chambers which had just been calibrated by Frank Day of NBS to energies ranging from 0.05 to 1.3 Mev and found to be independent of energy within ±5%. The source output of the two radium sources as measured with the thimble chambers agreed to within ±3% of the previous calibrations. Typical calibration curves for Du Pont 502, 510, 606, and 1290 are shown in Fig. 2. Although only the points obtained with the films in the NBS and AW badges are shown, the curves were constructed with the data from the NBS, AW, B-C, and EG&G badges. There is a small but consistent trend for the NBS badge points to lie below those of the AW badge, but the presumably similar EG&G badge gave points which tended to be slightly higher than the NBS points. However, 90% of the points for all badges were, in terms of exposure, within 5% of the composite curves shown.

2.4 Energy Dependence of the Film Badges

The energy dependence of the various film types used on these tests in the AW and NBS badges is shown in Fig. 3. The AW badge 606 and 1290 curves and all four NBS badge curves are based on measurements made by Ehrlich. The AW badge 502 and 510 curves were constructed using unfiltered film measurements made by Ehrlich and the true absorption coefficients given by White in NBS Report 1003. As may be seen, the AW badge

has a large overresponse for energies below 250 kev and the NBS badge has a large underresponse below 100 kev. If the spectrum of the measured gamma radiation contains components in the low energy region, resulting from the source spectrum or from multiple scattering in air, the AW badge would overevaluate and the NBS badge would underevaluate the exposure. This possible difference is in the direction of the generally observed discrepancy on previous operations.

The calculated response of filter B in the B-C badge to monochromatic radiation is shown in Fig. 3. Between 50 and 90 kev the area under this curve is equal to the area under a curve of unit sensitivity. The response for filter C is only slightly different from B, because of small differences in the relative amounts of the same elements. The discontinuities in the curve occur at the K-edges of the six elements making up the filter. As indicated in Fig. 3, measurements made with 40 to 75 kev monochromatic radiation gave excellent agreement with the calculated response; however, about 90 kev hard-filtered x-rays gave a much higher response than calculated. It was this latter feature which resulted in the use of thimble chambers in the field, rather than the B-C badge, as standards with which to compare the AW and NBS badges. Initial results from Bee showed the B-C badge to have a greater response than the AW badge, indicating the need for air-equilibrium material between the filters and the film. Subsequent use of such material resulted in obtaining the same response with the B-C badge as with the AW badge. Incidentally, measurements made by Ehrlich

after the operation demonstrated that the overresponse of the B-C badge above 90 kev was due to fluorescent radiation from the elements in the filter.

2.5 Victoreen Thimble Chambers

Victoreen thimble chambers have long been used in the laboratory as secondary standards for measuring exposures. The response of these instruments, as determined by Day of NBS, is essentially independent of energy above 30 kev. Both before and after the operation the chambers were calibrated to better than 5% accuracy with the 2.3 curie radium source. Tests for charge-leak were made in the laboratory and in the field over periods of 1 to 15 days. Table 1 lists the calibration and charge-leak correction factors for each chamber. Table 2 gives air densities, pressures, and temperatures and the applied pressure-temperature correction factors for the five tests on which measurements were made. Only six chambers, varying in full scale sensitivity from 2.5 to 250 r, were available for the Bee, Apple I, and Wasp Prime tests. Fifteen chambers were used on the Apple II shot and 13 on the Zucchini shot. For mechanical protection in the field, a cylindrical Lucite cap with a 1/16 in. wall and lined with aluminum foil, was placed over each chamber. This assembly was held approximately 10 in. above ground by a 2 in. square wood stake. The additional Lucite did not affect the response of the chambers, because it added an amount of air-like material which was insignificant compared with the amount of air already existing between

the source and the chambers. None of the chambers was damaged by the detonations, although two chambers located 2900 yd from ground zero on Apple II were accidently destroyed by an Army tank shortly before recovery.

3. Results

The exposures as a function of distance measured with chambers and film badges on the Bee, Apple I, Wasp Prime, Apple II, and Zucchini shots are given in Table 3. The calculated rd^2 (exposure times distance squared) values are given in Table 4 as a function of distance. The rd^2 vs d curves for the chambers, the AW badge, and the NBS badge are shown in Figs. 4, 5, and 6, respectively; also shown are the curves normalized to an air density of 1.055 g/l.

Table 5 gives the rd^2 values obtained from the normalized curves for each instrument at 3000 yd. The ratios of these rd^2 values measured on the Bee, Apple I, Wasp Prime, and Apple II tests to the rd^2 value measured on the Zucchini test are also given in the table, together with the yields obtained from these ratios by assuming a yield of 28 kt for Zucchini. The radiochemistry yields are given in the same table for purposes of comparison.

The following sets of exposure ratios are given in Table 6 for each film type, test, and each distance at which measurements were made: AW badge to chamber, NBS badge to chamber, and AW badge to NBS badge.

Results obtained with the B-C, British, and EG&G badges are given in Table 3.

4. Discussion of Results

4.1 Yield

The yield calculations in Table 5 show that the gamma radiation exposure on the Apple I, Wasp Prime, and Zucchini tests varied proportionately with yield, and that the chambers, AW badges, and NBS badges scaled equally well. Since there is no reason connected with the Apple II device itself that should prevent scaling, the apparent increase of exposure per kiloton is probably due to the fission cloud, which was observed to pass over the instrument line. The resultant ground pattern of the contamination strengthens this conclusion. Once before, on the

4.2 Comparison of Chambers and Film Badges

The various ratios for each instrument appearing in Table 6 were averaged for all distances and the results are given in Table 7. Thus there are averages of AW to chamber, NBS to chamber, and AW to NBS for each film type and for each test. Shown in Table 8 are the ratios for

the various film, film badge, and chamber combinations averaged over all distances and tests, these being called pooled averages. No pooled averages with Apple II measurements are given because of the previously mentioned inconsistency due to the fission cloud; had these data been included the AW to chamber and the NBS to chamber ratios would have been somewhat lower. Although there is considerable scatter in the data, there appear to be trends from which certain conclusions may be drawn.

With the exception of the Apple II measurements, the AW badge gave consistently higher values than the chambers. The 502 and 510 films were about 10% higher, and the 606 and 1290 about 20% higher than the chambers. In the NBS badge the 502 films averaged about 7% lower than the chambers, the 510 about 19% lower, the 606 about 10% lower, and the 1290 essentially the same as the chambers.

Because of a lack of thimble chambers there were more AW/NBS values than ratios involving thimble chambers.

In every case, the exposures measured in the AW badge were higher than those measured in the NBS badge, the average difference varying with film types as follows: the 502 film, 16% higher; 510, 36%; 606, 34%; and 1290, 21%. The Apple II data are not included in the weighted averages used to obtain these differences.

The few measurements made with the three other badges indicate that the B-C and British badges gave essentially the same results as the AW badge, and the EG&G badge gave about the same results as the NBS badge.

4.3 Interpretation in Terms of Energy Dependence

Figure 3 shows that between 40 and 100 kev the AW badge is much more sensitive than the NBS badge, more than 100 to 1 at 40 kev. Since the largest difference found between the two badges was 36%, the spectrum seen by the badge contains very little energy in this range. This same conclusion is obtained by considering that the B-C and AW badges gave the same measured values even though the AW badge is as much as 20 times more sensitive than the B-C badge in the 40 to 100 kev region.

In the 100 to 250 kev range the AW and B-C badges have an over-response. A significant amount of energy in this region might account for the 10 to 20% greater response relative to the thimble chambers which these badges exhibited. If significant energy components exist in this range, the NBS badge would give lower exposures than the AW and B-C badges, a result actually obtained. However, the ratios obtained with the various film types in the NBS badge are not consistent with their energy dependence curves. From these curves one would have expected the 510 film to read higher than the 606 film, and the 606 film to read higher than the 502 and 1290 films, but precisely the opposite trend was found. Thus, if the differences found between the various film types in the NBS badge are due to radiation from 100 to 250 kev, the energy dependence curves must be invalid in this energy range.

There are small differences in film response to 10 Mev betatron radiation but these are not the correct magnitude nor direction to account for the differences obtained.

Thus, it appears as though nearly all the gamma radiation had an energy greater than 250 kev, and the presence of only extremely small amounts of radiation between 40 and 250 kev would be sufficient to give the small differences found.

4.4 The LASL and ESL Discrepancy on Previous Tests

4.4.1 LASL Measurements

As mentioned in Section 2.3, there has been in the past a 13% error in LASL gamma radiation vs distance measurements due to calibration. Assuming the thimble chambers measured the exposure correctly on the Teapot operation, there has been an additional error in the LASL measurements, probably due to energy dependence, which amounts to 10% with the 502 and 510 films and 20% with the 606 and 1290 films. Thus, in comparing the Teapot thimble chamber measurements to the AW badge film measurements made on previous tests, one should expect the film measurements to be high at the near distances by about 33% and high at the far distances by 23%. The Ranger F film measurements have been used as a "standard" to which subsequent measurements have been scaled; Fig. 7 shows the Ranger F and the Zucchini rd^2 vs d curves normalized to an air density of 1.055 g/l. At 2000 yards the Ranger F curve is 30% higher than the Zucchini curve and at 3000 yards it is 22% higher.

4.4.2 ESL Measurements

Assuming the thimble chambers measured the exposure correctly, there has been an error in the ESL measurements, presumably due to energy

dependence, which amounts to 10% with the 606 film, 19% with the 510, 7% with the 502, and no error with the 1290. No measurements were made with the 508 film.

The correction factors given above were applied to a few tests on which both ESL and LASL had made measurements. Although the exposure values were in much better agreement after correction, inconsistent discrepancies were still apparent. For example, on the Tumbler 2 test the corrected LASL measurements remained higher than the corrected ESL measurements; on the Upshot 5 test the measurements were in agreement, and on the Snapper 2 test the ESL measurements were higher than the LASL measurements. The largest discrepancies occur in the ranges in which ESL used Du Pont 508.

ESL's preliminary Teapot report, ITR-1115, does not include Apple II and Zucchini results, but there are a few distances on the Bee, Apple I, and Wasp Prime tests where measurements can be compared. Table 9 shows the exposure values obtained by ESL in the NBS badge, film type unspecified, and the LASL measurements in the NBS badge. The reasonable agreement lends encouragement to the idea that with further measurements on the next Nevada operation, it should be possible to determine accurately the manner in which exposure vs distance varies with yield. Correction factors can then be applied to data collected on previous tests.

TABLE 1 THIMBLE CHAMBER CORRECTION FACTORS FOR SENSITIVITY AND CHARGE LEAKAGE

Chamber	Sensitivity correction factor*	Charge leakage correction factor per 24 hr
2.5 r #1	1.09	< 1.01
10 r #1	1.30	< 1.01
10 r #2	1.07	< 1.01
25 r #1	1.17	< 1.01
25 r #2	1.09	< 1.01
25 r #3	1.12	< 1.01
25 r #4	1.17	< 1.01
25 r #5	1.20	< 1.01
25 r #6	1.18	< 1.01
100 r #3	1.02	< 1.01
100 r #4	1.04	1.02
100 r #5	1.07	1.015
100 r #6	1.04	1.05
100 r #7	1.08	1.01
250 r #1	0.82	1.07
250 r #2	0.87	1.05

*Preponderance of correction factors greater than 1 could arise from using an electrometer with a lower sensitivity than the chambers were designed for. This possibility was not determined.

TABLE 2 AIR DENSITIES, PRESSURES, TEMPERATURES, AND PRESSURE-TEMPERATURE CORRECTION FACTORS APPLIED TO VICTOREEN THIMBLE CHAMBERS

Shot	Air densities, g/l: Ground zero	Air densities, g/l: Burst height	Air densities, g/l: Average	Ground pressure, mm	Ground temperature, °K	Pressure-temperature correction factor
Bee	1.162	1.088	1.125	667.2	266	1.027
Apple I	1.107	1.043	1.075	652.7	284	1.121
Wasp Prime	1.043	1.032	1.038	653.2	284	1.121
Apple II	1.100	1.035	1.068	653.8	276	1.086
Zucchini	1.104	1.081	1.092	656.3	276	1.084

TABLE 3 EXPOSURE VS DISTANCE FOR CHAMBERS AND FILM BADGES

Distance, yd	Thimble chambers Number	Exposure, r	AW badge exposures, r 502	510	606	1290	NBS badge exposures, r 502	510	606	1290	B-C badge exposures, r 502	510	606	1290	EG&G badge exposures, r 502	510	606	1290	British badge exposures, r (PM 3)
Readings taken on Bee shot																			
1700	250 r #2	61.2			82	84			64	70									
2000	100 r #3	25.0			26	28			18	20									
2300	25 r #3	8.51	8.2	8.3			7.3	6.2			8.7	9.0							
2500	25 r #1	4.87	4.5	4.2			4.2				5.0	4.9							
2800	10 r #2	1.75	2.0				1.55				2.25								
3100	25 r #1	0.661	0.82				0.72				0.98								
Readings taken on Apple I shot																			
2000					46	45			36	36									
2200	250 r #2	14.8		24	23	23		12	14	16		20	19	19					
2400	100 r #3	10.8	10	11			9.0	7.6											
2600	25 r #3	5.52	5.9	5.7			5.0	4.2											
2800	25 r #1	3.15	3.4	3.3			2.8	2.3			3.4	3.3							
3000	10 r #2	5.76	1.9	1.7			1.6	1.5			1.9	1.7							
3300	25 r #1	0.758	1.0				0.82				1.0								
Readings taken on Wasp Prime shot																			
1250						260			200	220									
1450					110	110			79	86									
1650	25 r #3	33.5			46	47			35	37									
1850	25 r #1	17.4		23	22	22		15.5	16	17			22	22					
2040	10 r #2	11.6	10	11.5	12	12	9.2	8.0			10	10							
2240			5.7	5.4			4.8	3.8			5.4	5.4							
2440	25 r #1	1.98	2.9	2.7			2.5	1.8			2.7	2.7							
2640			1.55	1.6			1.4	1.0											
2840			0.93				0.73												
3040			0.50				0.60												

TABLE 3 EXPOSURE VS DISTANCE FOR CHAMBERS AND FILM BADGES (continued)

Distance, yd	Thimble chambers Number	Exposure, r	AW badge exposures, r 502	510	606	1290	NBS badge exposures, r 502	510	606	1290	B-C badge exposures, r 502	510	606	1290	EG&G badge exposures, r 502	510	606	1290	British badge exposures, r (PM 3)
Readings taken on Apple II shot																			
1500						1000				840									
1600						550				410									
1700						375				320									
1800	250 r #1	202				250			180	200			250			180	200		
1900	250 r #2	152			160	170			110	135		170	170			120	140		
2000	100 r #5	114			110	110			82	99		105	115			82	lost		
2100	100 r #6*				76	79			52	63		78	78			56	64		
2200	100 r #7	101			54	55			38	46						37	46		
2300	100 r #4	56.8			42	41			25	33						28	32		
2400	100 r #3	29.6			23	25		18	19	20					20	20	20		
2500	25 r #1	21.1		19	19	20		13							15				
2600	25 r #3	16.0		14.5				11											
2700	25 r #4	13.2		12				8.4											10.5
2800	25 r #5	11.0	9.3	8.7			7.3	6.2											6.5
2900	25 r #6**		6.5	6.6			5.5	4.7											5.4
	10 r #2**																		
3000	10 r #1	5.84	5.1	5.0			4.0	3.5											3.3
3200			2.5	2.6			2.1												
3400	25 r #1	1.24	1.5				1.2												
Readings taken on Zucchini shot																			
1500						600				530									
1600						400				350									
1700						250				230									
1800					150	160			130	150									
1900	250 r #2*				105	105			77	90									
2000	250 r #1	59.8			72	72			55	63									
2100	100 r #5	44.6			50	51			38	42									
2200	100 r #6	31.1			35	37			27	30									
2300	100 r #7*				25	25		20	20	22									
2400	100 r #4	17.6		19	20	20		13.5											
2500	100 r #3	12.1		14				11											
2600	25 r #1	9.51	9.6	10			8.4	8.0											
2700	25 r #3	5.59	7.0	7.4			6.3	6.0			7.2	7.4							
2800	25 r #4	5.08	5.4	5.6			4.7	4.4			5.4	5.4							
2900	25 r #5	3.38	4.0	4.0			3.5	3.1			4.0	4.0							
3000	10 r #1	2.82	3.0	3.0			2.6	2.3			3.0	3.0							
3200			1.65	1.7			1.45												
3400	25 r #1	2.59	0.88				0.78												

* Off scale.
** Chamber broken.

TABLE 4 CALCULATED VALUES OF EXPOSURE TIMES DISTANCE SQUARED VS DISTANCE

Distance, yd	Thimble chamber (x 10^6)	AW badge (x 10^6)				NBS badge (x 10^6)			
		502	510	606	1290	502	510	606	1290
		Calculated values for Bee shot							
				240	243			180	200
1700	180			100	110			70	80
2000	100					39	33		
2300	45	43	44			26			
2500	30	28	26			13			
2800	14	16				6.9			
3100	6.4	7.9							
		Calculated values for Apple I shot							
				180	180			144	140
2000			120	110	110		58	68	77
2200	81	58	63			52	44		
2400	62	40	38			34	28		
2600	37	27	26			22	18		
2800	25	17	15			14	14		
3000	52	11				8.9			
3300	8.2								
		Calculated values for Wasp Prime shot							
					410			310	340
1250				230	230			170	180
1450				120	130			95	100
1650	91		79	75	75		53	55	59
1850	60		48	50	50	38	33		
2040	61	42	27		15	24	19		
2240		29				11			
2440	12	17	16			9.8	7.0		
2640		11	11			5.9			
2840		7.5				3.7			
3040		4.6							

TABLE 4 CALCULATED VALUES OF EXPOSURE TIMES DISTANCE SQUARED VS DISTANCE (continued)

Distance, yd	Thimble chamber (x 10^6)	AW badge (x 10^6)				NBS badge (x 10^6)			
		502	510	606	1290	502	510	606	1290
		Calculated values for Apple II shot							
1500					2300				1900
1600					1400				1100
1700					1100				920
1800	650				810			580	650
1900	550			580	610			400	490
2000	460			440	440			330	400
2100				340	350			230	280
2200	490			260	270			180	220
2300	300			220	220			130	180
2400	170			130	140		100	110	120
2500	130		119	120	120		81		
2600	110		98				74		
2700	96		88				61		
2800	86	73	68			57	49		
2900		55	56			46	40		
3000	53	46	45			36	32		
3200		26	27			22			
3400	14	17				14			
		Calculated values for Zucchini shot							
1500					1400				1200
1600					1000				900
1700					720				660
1800				490	520			420	490
1900				380	380			280	320
2000	240			290	290			220	240
2100	200			220	220			170	180
2200	150			170	180			130	140
2300			110	130	130		110	110	120
2400	100		88	120	120		78		
2500	76		68				69		
2600	64	65	54			56	54		
2700	41	51	44			46	44		
2800	40	42	34			37	34		
2900	28	34	27			29	26		
3000	25	27	17			23	21		
3200		17	17			15			
3400	30	10				9.0			

TABLE 5 COMPARISON OF YIELDS

Shot	rd^2 ($\times 10^6$) at 3000 yd	Ratio	Yield, kt	Radiochem. yield, kt
		Calculated from thimble chambers		
Bee	13.0	0.42	11.8	8.1
Apple I	17.0	0.55	15.4	15.5
Wasp Prime	3.6	0.116	3.3	3.2
Apple II	48.0	1.55	43.3	30
Zucchini	31.0	1.00	28	28
		Calculated from AW badges		
Bee	14.0	0.42	11.8	8.1
Apple I	18.5	0.55	15.4	15.5
Wasp Prime	4.1	0.122	3.4	3.2
Apple II	48.0	1.43	40.0	30
Zucchini	33.5	1.00	28	28
		Calculated from NBS badges		
Bee	11.5	0.43	12.0	8.1
Apple I	15.0	0.56	15.7	15.5
Wasp Prime	3.1	0.115	3.2	3.2
Apple II	37.5	1.39	38.8	30
Zucchini	27.0	1.00	28	28

TABLE 6 EXPOSURE RATIOS FOR THIMBLE CHAMBER, AW BADGES, AND NBS BADGES

Distance, yd	AW badge/NBS badge				AW badge/thimble chamber				NBS badge/thimble chamber			
	502	510	606	1290	502	510	606	1290	502	510	606	1290
Exposure ratios for Bee shot												
1700			1.28	1.20			1.34	1.37			1.04	1.14
2000			1.44	1.40			1.04	1.12			0.72	0.80
2300	1.12	1.34			0.96	0.98			0.86	0.73		
2500	1.07				0.92	0.86			0.86			
2800	1.21				1.14				0.94			
3100	1.14				1.24				1.09			
Exposure ratios for Apple I shot												
2000		2.00	1.28	1.25								
2200		1.50	1.64	1.44		1.43	1.37	1.37		0.71	0.83	0.95
2400	1.11	1.45			0.92	1.02			0.83	0.70		
2600	1.18	1.36			1.07	1.03			0.90	0.76		
2800	1.21	1.43			1.08	1.05			0.89	0.73		
3000	1.19	1.13			0.33*	0.30*			0.28*	0.26*		
3300	1.22				1.31				1.08			
Exposure ratios for Wasp Prime shot												
1250				1.18								
1450			1.39	1.28			1.37	1.40			1.04	1.10
1650			1.31	1.27			1.26	1.26		0.89	0.92	0.98
1850			1.38	1.29		1.32						
2040	1.09	1.44			0.68	0.79	0.82	0.82	0.63	0.55		
2240	1.19	1.42										
2440	1.16	1.50			1.46	1.36			1.26	0.91		
2640	1.11	1.60										
2840	1.27											
3040	1.25											

TABLE 6 EXPOSURE RATIOS FOR THIMBLE CHAMBER, AW BADGES, AND NBS BADGES (continued)

Distance, yd	AW badge/NBS badge				AW badge/thimble chamber				NBS badge/thimble chamber			
	502	510	606	1290	502	510	606	1290	502	510	606	1290
					Exposure ratios for Apple II shot							
1500				1.19								
1600				1.34								
1700				1.17								
1800				1.25				1.24			0.89	0.99
1900			1.45	1.26			1.05	1.12			0.72	0.89
2000			1.34	1.11			0.96	0.96			0.72	0.87
2100			1.46	1.25								
2200			1.42	1.20			0.53*	0.54*			0.38*	0.46*
2300			1.68	1.24			0.74	0.72			0.44	0.58
2400			1.21	1.25			0.78	0.84		0.61	0.64	0.68
2500		1.46				0.90	0.90	0.95		0.62		
2600		1.31				0.91				0.69		
2700		1.43				0.91				0.64		
2800	1.27	1.40			0.85	0.79			0.66	0.56		
2900	1.18	1.40										
3000	1.28	1.43			0.87	0.86			0.68	0.60		
3200	1.19											
3400	1.25				1.21				0.97			

TABLE 6 EXPOSURE RATIOS FOR THIMBLE CHAMBER, AW BADGES, AND NBS BADGES (continued)

Distance, yd	AW badge/NBS badge				AW badge/thimble chamber				NBS badge/thimble chamber			
	502	510	606	1290	502	510	606	1290	502	510	606	1290
					Exposure ratios for Zucchini shot							
1500				1.13								
1600				1.14								
1700				1.09								
1800			1.15	1.07								
1900			1.36	1.17								
2000			1.31	1.14			1.20	1.20			0.92	1.05
2100			1.32	1.21			1.12	1.14			0.85	0.94
2200			1.30	1.23			1.12	1.19			0.87	0.96
2300			1.25	1.13								
2400		1.41				1.08	1.14	1.14		0.77		
2500		1.27				1.16				0.91		
2600	1.14	1.25			1.01	1.05			0.88	0.84		
2700	1.11	1.23			1.25	1.32			0.91	1.07		
2800	1.15	1.27			1.06	1.10			0.92	0.87		
2900	1.14	1.29			1.18	1.18			1.04	0.92		
3000	1.15	1.30			1.06	1.06			0.92	0.82		
3200	1.14											
3400	1.13				3.40*				3.01*			

* Not included in averages of Table 7.

TABLE 7 AVERAGE RATIOS, NUMBER OF MEASUREMENTS, AND STANDARD DEVIATIONS

Shot	Film 502		Film 510		Film 606		Film 1290	
	No. of values averaged	Average and standard deviation	No. of values averaged	Average and standard deviation	No. of values averaged	Average and standard deviation	No. of values averaged	Average and standard deviation
Ratio of AW badge to thimble chamber								
Bee	4	1.06 ± 0.08	2	0.92 ± 0.06	2	1.19 ± 0.15	2	1.24 ± 0.13
Apple I	4	1.10 ± 0.08	4	1.13 ± 0.10	1	1.37	1	1.37
Wasp Prime	2	1.07 ± 0.39	3	1.16 ± 0.19	3	1.15 ± 0.17	3	1.16 ± 0.18
Apple II	3	0.98 ± 0.12	5	0.87 ± 0.03	5	0.89 ± 0.06	6	0.97 ± 0.08
Zucchini	5	1.11 ± 0.04	7	1.13 ± 0.03	4	1.14 ± 0.02	4	1.17 ± 0.02
Ratio of NBS badge to thimble chamber								
Bee	4	0.94 ± 0.06	1	0.73	2	0.88 ± 0.16	2	0.97 ± 0.17
Apple I	4	0.92 ± 0.06	4	0.72 ± 0.02	1	0.83	1	0.95
Wasp Prime	2	0.94 ± 0.31	3	0.78 ± 0.12	2	0.98 ± 0.06	2	1.04 ± 0.06
Apple II	3	0.77 ± 0.10	6	0.62 ± 0.02	5	0.68 ± 0.07	5	0.80 ± 0.08
Zucchini	5	0.93 ± 0.07	7	0.89 ± 0.04	3	0.88 ± 0.02	3	0.98 ± 0.04
Ratio of AW badge to NBS badge								
Bee	4	1.14	1	1.34	2	1.34	2	1.30
Apple I	5	1.18	5	1.37	2	1.46	2	1.33
Wasp Prime	6	1.18	4	1.49	3	1.36	4	1.25
Apple II	5	1.23	6	1.40	6	1.43	10	1.23
Zucchini	7	1.14	7	1.29	6	1.28	9	1.15

TABLE 8 POOLED AVERAGES*

Badge	Film 502		Film 510		Film 606		Film 1290	
	No. of values averaged	Average and standard deviation	No. of values averaged	Average and standard deviation	No. of values averaged	Average and standard deviation	No. of values averaged	Average and standard deviation
AW/TC	15	1.09 ± 0.05	16	1.11 ± 0.05	10	1.18 ± 0.05	10	1.20 ± 0.05
NBS/TC	15	0.93 ± 0.04	15	0.81 ± 0.03	8	0.90 ± 0.04	8	0.99 ± 0.04
AW/NBS	22	1.16	17	1.36	13	1.34	17	1.21

*Apple II not included.

TABLE 9 COMPARISON OF ESL AND LASL FILM MEASUREMENTS MADE WITH THE NBS BADGE ON TEAPOT

Shot	Distance, yd	ESL results, r	LASL results, r		
			606	1290	510
Bee	1700	74.0	64	70	
	2000	18.0	18	20	
Apple I	2000	32	36	36	
	2200	14	14	16	12
Wasp Prime	1250	200	200	220	
	1450	85	79	86	
	1650	34	35	37	
	1850	15	16	17	15.5

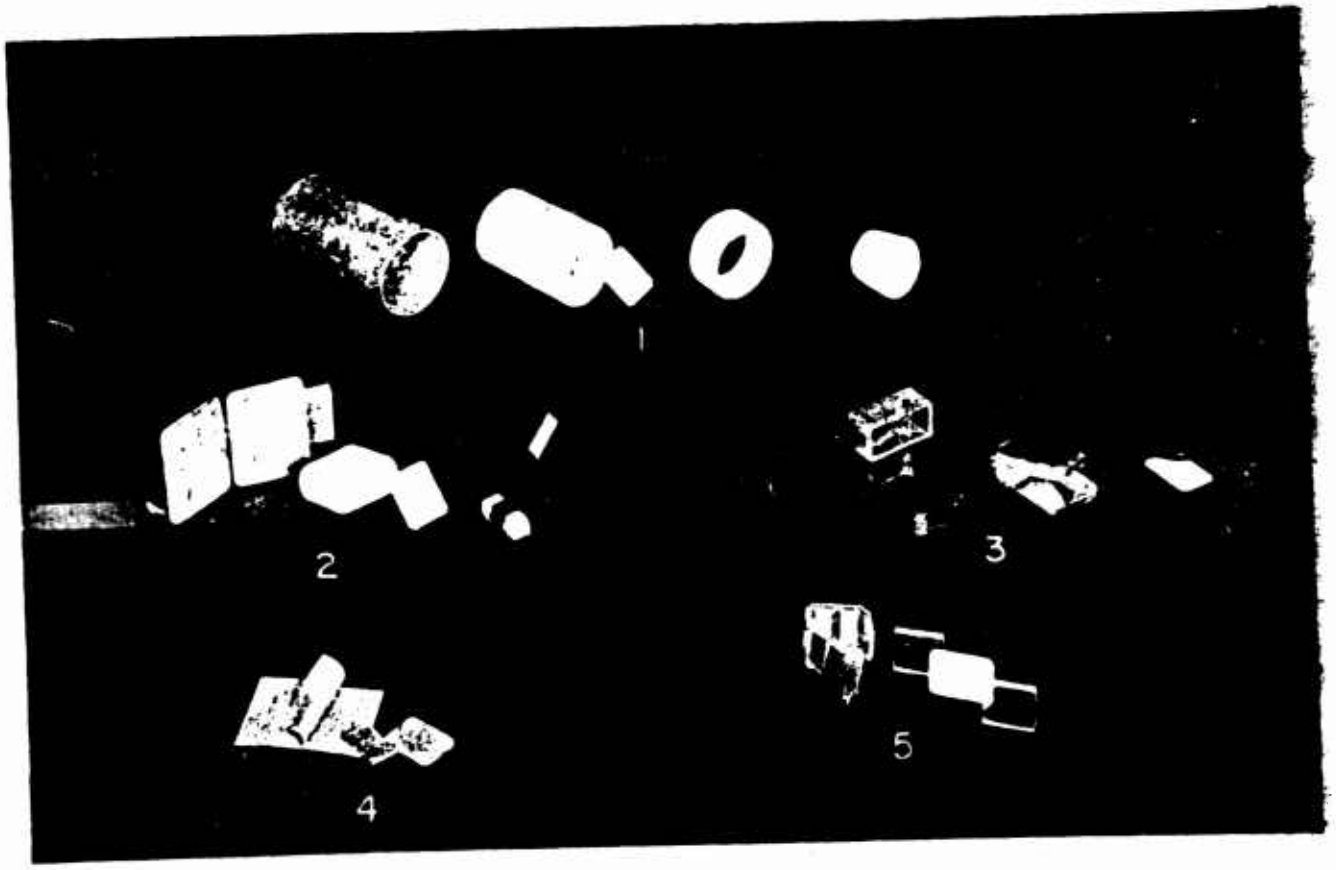

Fig. 1. Types of film badges used during Teapot: (1) aluminum-wood badge, (2) EG&G badge, (3) NBS badge, (4) British badge, and (5) B-C badge.

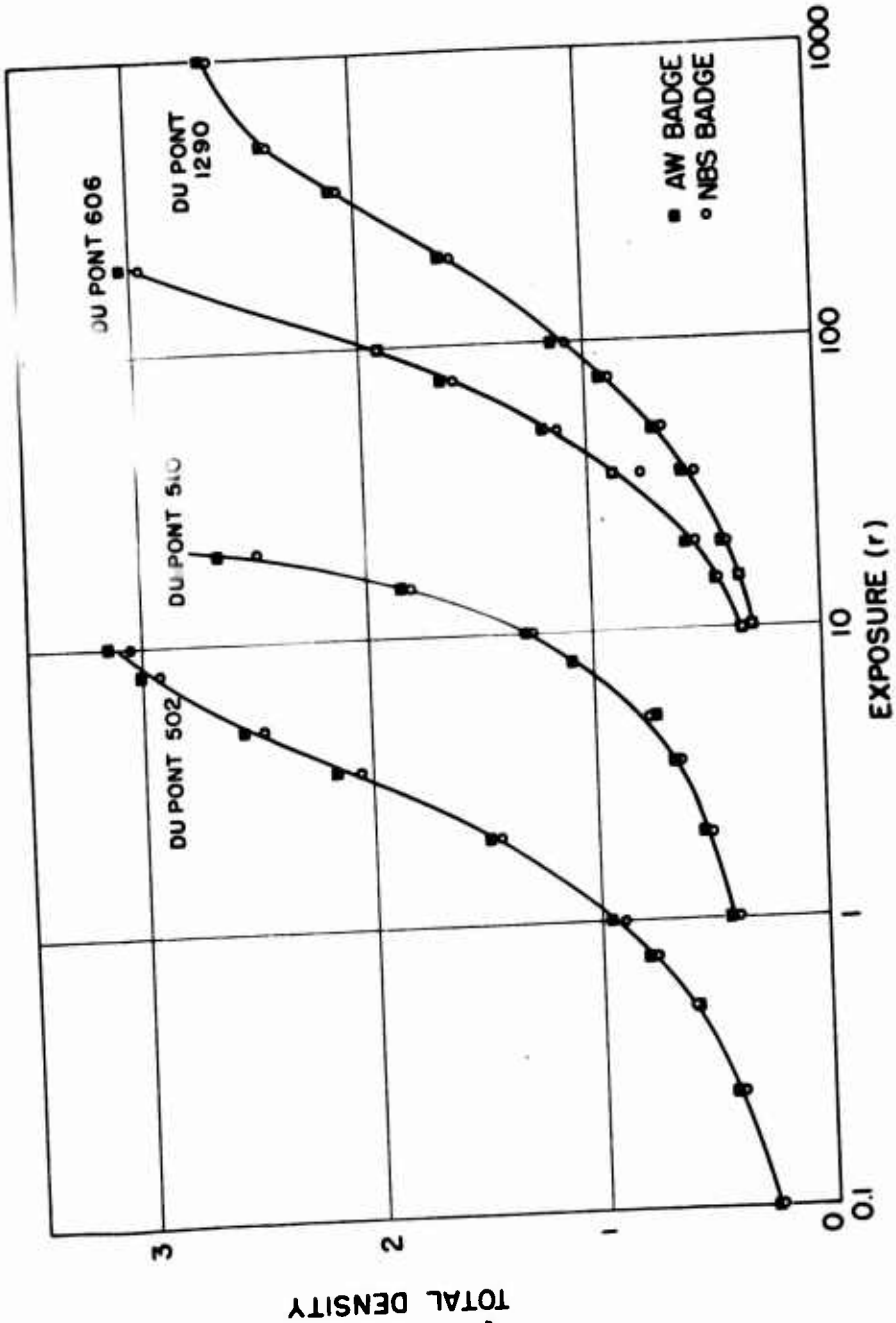

Fig. 2. Radium calibration curves.

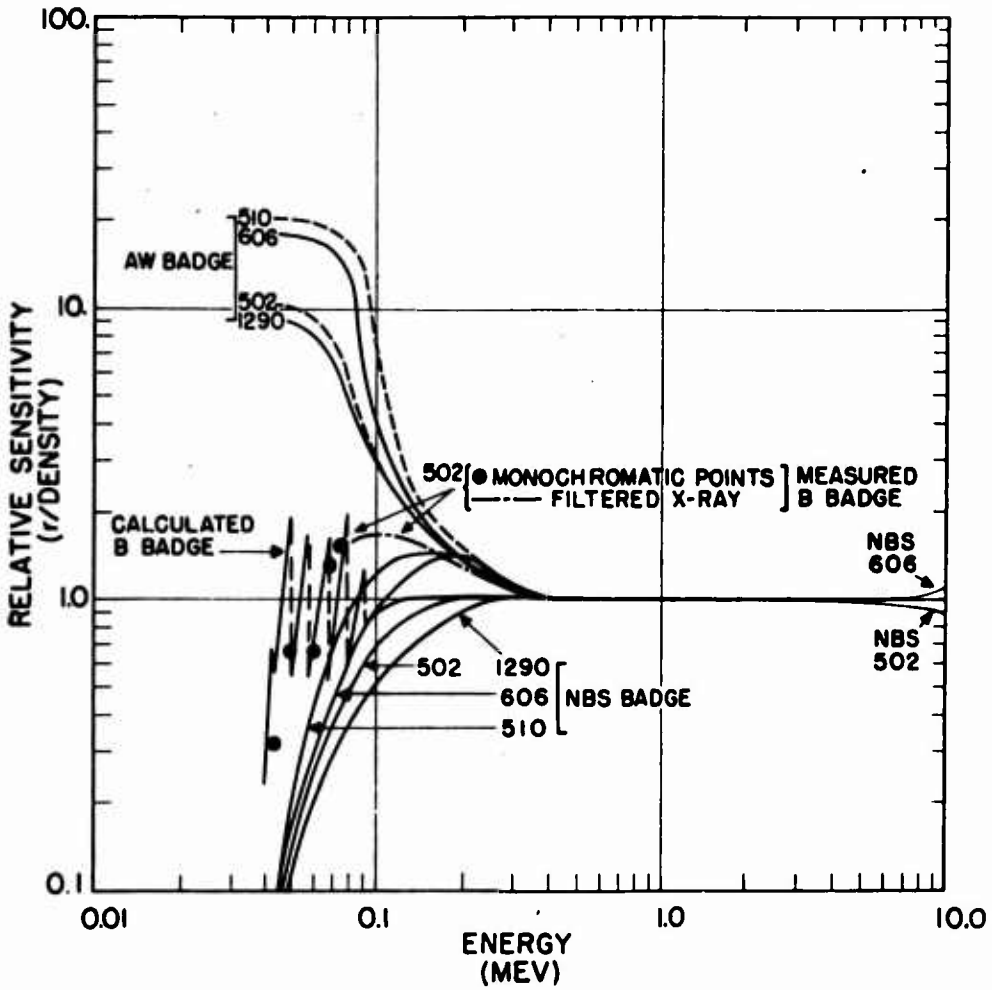

Fig. 3 Energy dependence of AW, NBS, and B section of B-C badge.

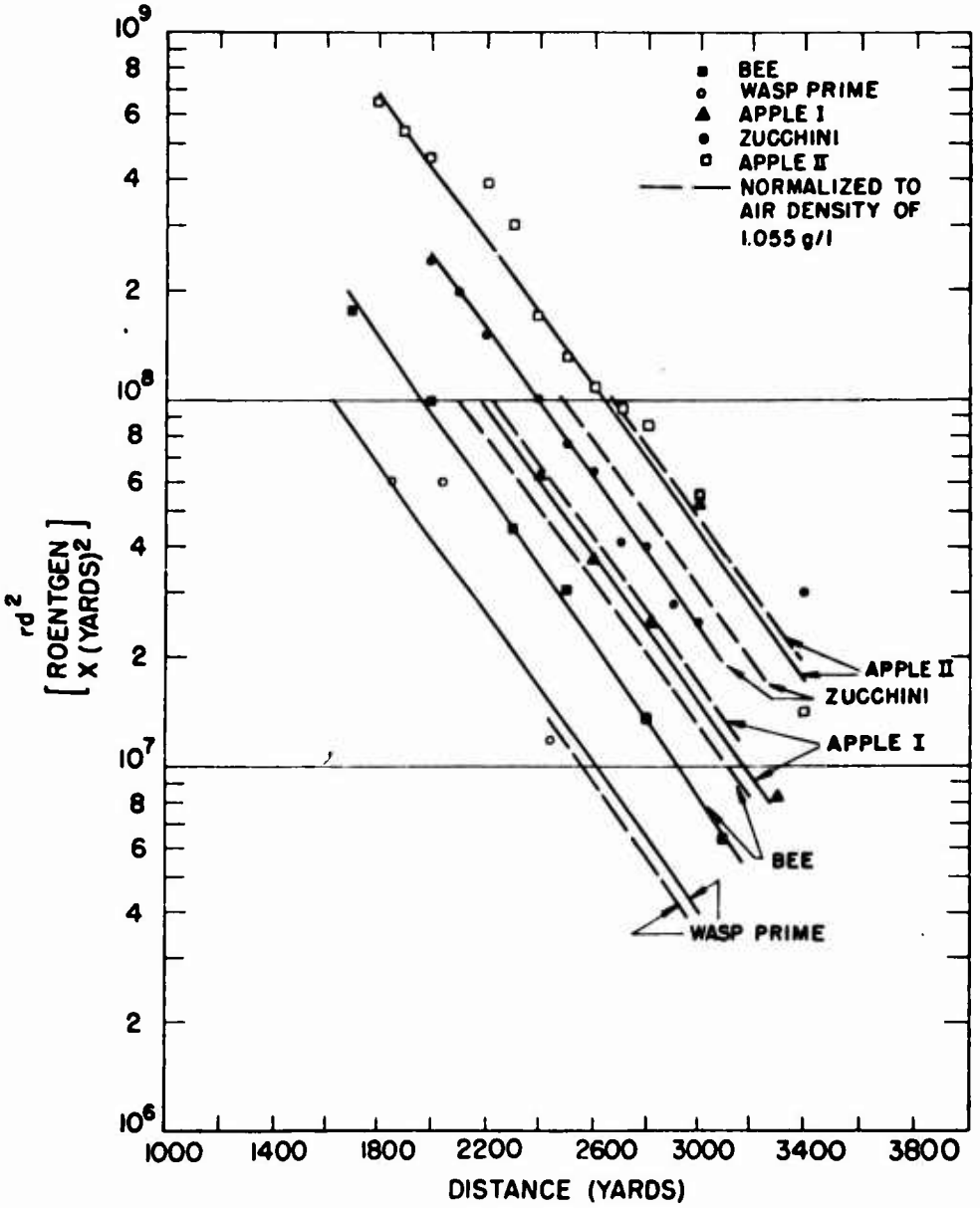

Fig. 4 Gamma radiation exposure times distance squared vs distance, measured with thimble chambers.

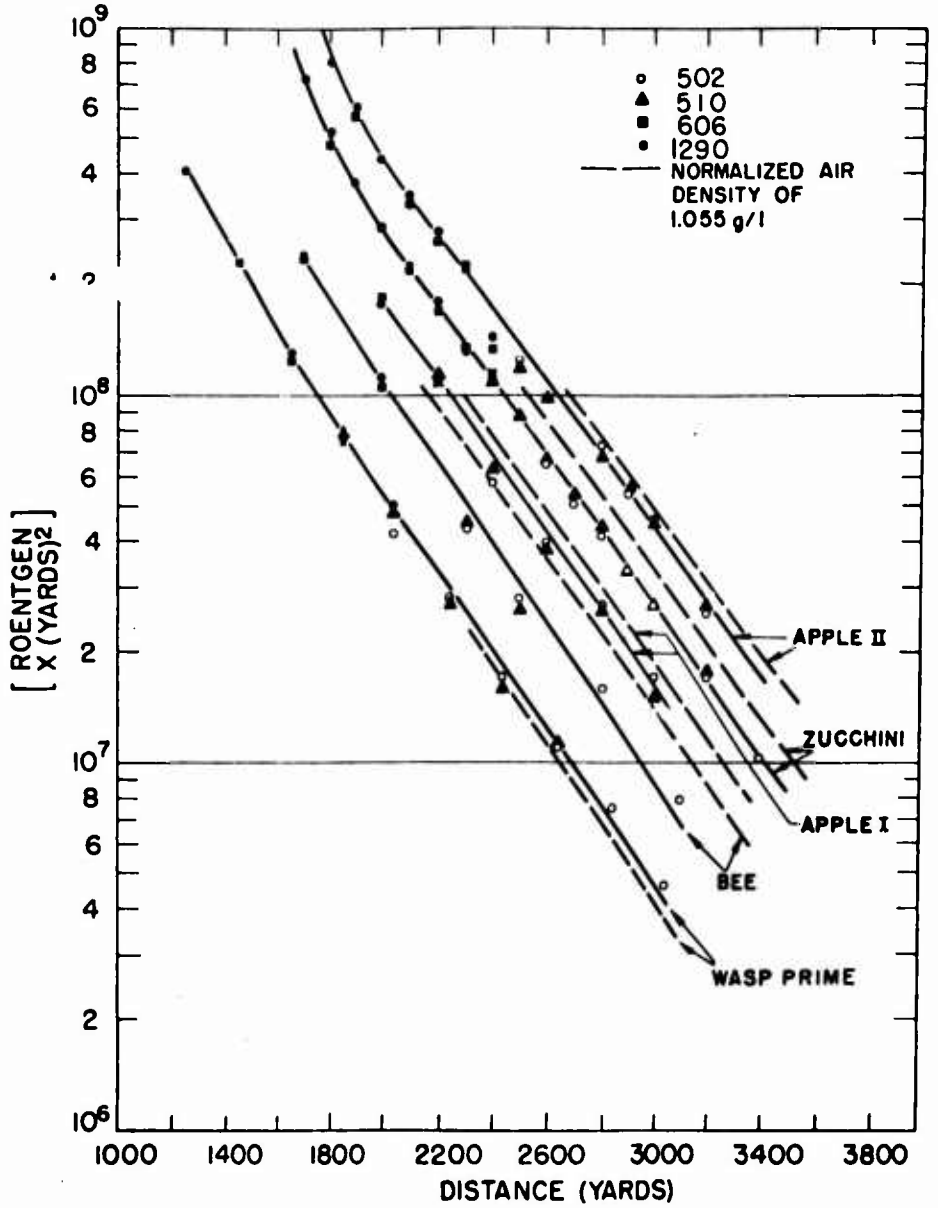

Fig. 5 Gamma radiation exposure times distance squared vs distance, measured with AW badges.

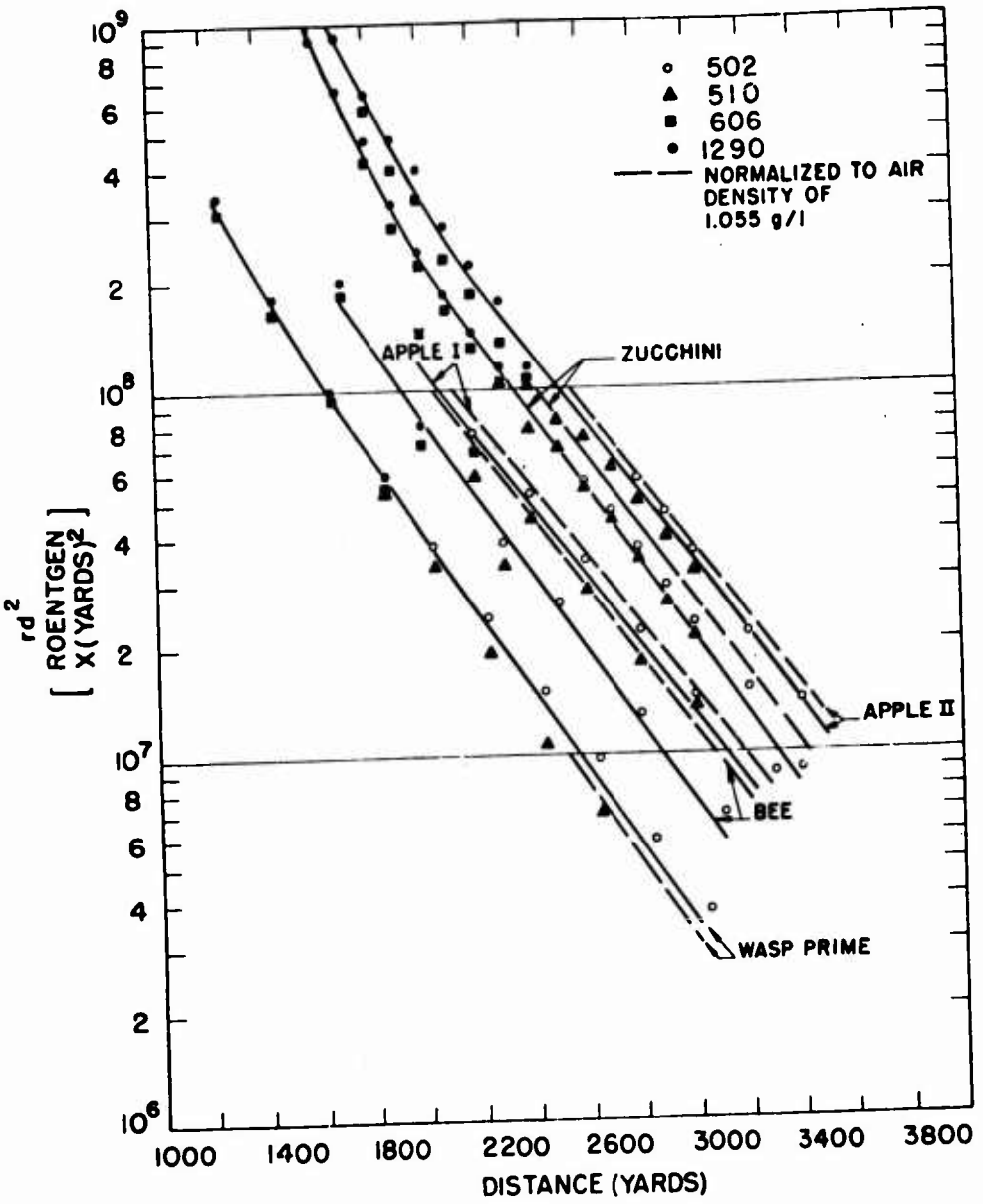

Fig. 6 Gamma radiation exposure times distance squared vs distance, measured with NBS badges.

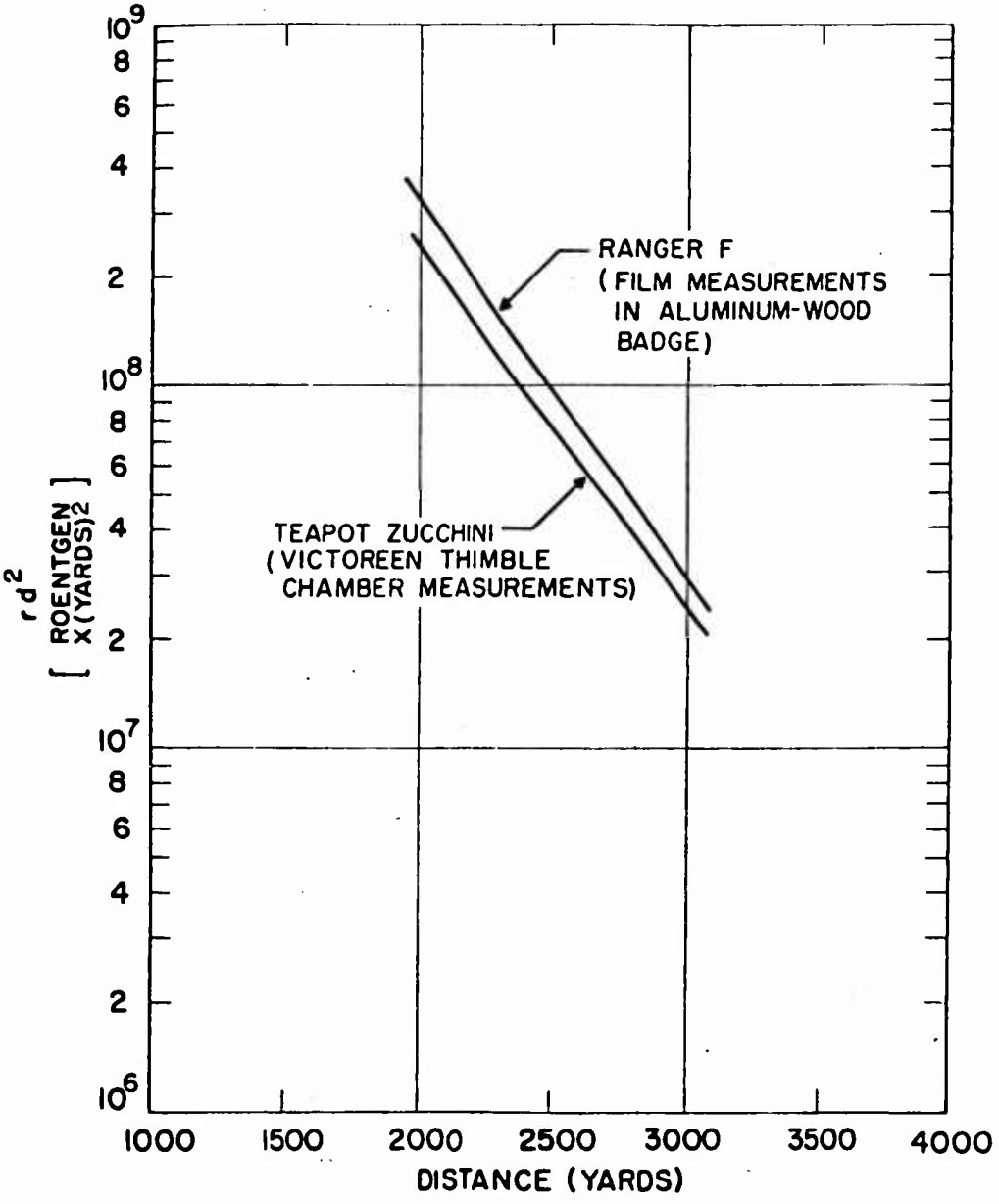

Fig. 7 Comparison of Teapot Zucchini and Ranger F rd^2 vs d curves normalized to an air density of 1.055 g/l and a yield of 22 kt.